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(FINAL REPORT)

S-3000X PROTOTYPE HF DIGITAL DATA MODEM

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DEPUTY FOR ENGINEERING AND TECHNOLOGY
ELECTRONIC SYSTEMS DIVISION
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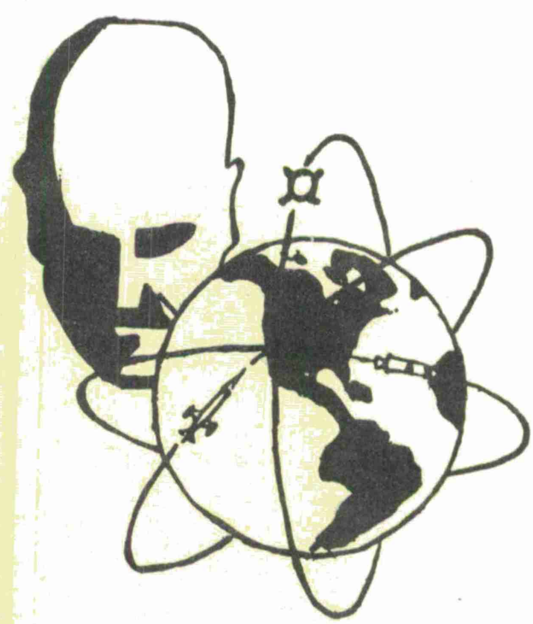

(Prepared under Contract No. AF 19 (628)-3281 by the General Atronics Corp., 1200 East Mermaid Lane, Philadelphia, Pa., 19118.)

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FOREWORD

This Technical Documentary Report No. ESD-TDR-64-679 describes the S-3000X Prototype HF Digital Data Terminal. This equipment was constructed under Contract No. AF 19(628)-3281 by General Atronics Corporation, 1200 East Mermaid Lane, Philadelphia, Pa. This report has been assigned the General Atronics Corporation Report No. 1367-2004-10.

ABSTRACT

The S-3000X Prototype HF Digital Data Modem is a breadboard test model which provides a simulation of 3000 b/s data transmission on a high frequency radio voice circuit while actually transmitting 1200 b/s or 750 b/s. A provision has been made for redundant transmission at lower rates for comparison purposes. This final report covers the system specification, critical subsystem and component specifications, laboratory evaluation, a performance analysis and a reliability analysis of the S-3000 modem.

This technical documentary report has been reviewed and is approved.

ROY D. RAGSDALE
Col., USAF
Director, Aerospace Instrumentation

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1.0 Introduction

1.1 S-3000X Digital Data Terminal

The S-3000X modem is an experimental breadboard test model of an HF digital data modem. It accepts input data in serial binary form. Although its actual maximum data transmission rate is 1200 b/s, the transmission simulates operation at 3000 b/s. The equipment is expandable to operate at 3000 b/s. The general design of the S-3000X is based upon the principles which have been employed in the breadboard experimental model of the KATHRYN HF variable data rate communication system. However, significant modification to the system parameters and to the detection process will be necessary in order to extend the data handling capacity to 3000 bits/second. Important design changes were made in order to allow operation at this high data rate without resorting to increased redundancy even where wide multipath dispersion is encountered. In particular, the design parameters of the S-3000X were chosen to provide a 6 millisecond guard time between received signal elements, whereas the optimum guard time for a system designed to employ a variable data rate would be on the order of 1 millisecond. The bandwidth inefficiency which results from this large guard time required the modification of the modem detection process. Signal components which would normally be used for pilot or probe energy were required to transmit information. These components were subsequently used for reference derivation. However, a decision feedback process was required which is somewhat less reliable than a correlation detection process with a known local reference such as used in KATHRYN. The simulated S-3000X system actually operated at a signal frame rate of 37.5 frames per second, as contrasted with the KATHRYN frame sample rate of 75 bits/second. This decrease in frame rate causes a 2:1 decrease in ionospheric measurement sampling rate which could introduce significant errors under rapid fading conditions. The combination of increased data rate and guard time of the S-3000X were achieved, therefore, at a significant cost in reliability of communication when compared with the KATHRYN variable data rate system.

2.0 System Specification

2.1 Transmitter

2.1.1 Data Sources

a) 1200 bits per second serial synchronous data stream, nonredundant (techniques simulate 3000 b/s transmission)
b) 750 bits per second serial synchronous data stream, nonredundant (simulation of 3000 b/s)
c) 375 bits per second serial synchronous data stream, second order redundancy (simulation of 1500 b/s)
d) 150 bits per second serial synchronous data stream, fourth order redundancy (simulation of 750 b/s)
e) 75 bits per second serial synchronous data stream, eighth order redundancy (simulation of 375 b/s)

2.1.2 Output Signal

a) At 1200 bits per second, 2.4 kc baseband signal compatible with TD-97 multiplexer at 0 dbm level.
b) At 750 bits per second or less a 1.8 kc baseband signal compatible with TD-97 multiplexer at 0 dbm level.

2.1.3 Pseudo-random Modulation

All transmitted components modulated by internal pseudo-random sequence generator.

2.1.4 Timing Reference

Internal timing source; stability, 1 part in 10^8 per day.

2.1.5 Physical Size

Two six-foot relay rack cabinets.

2.2 Receiver

2.2.1 Inputs

Two baseband audio inputs from space or frequency diversity receivers at 0 dbm level.

2.2.2 Data Output

a) 1200 bits per second serial data stream
b) 750 bits per second serial data stream
c) 375 bits per second serial data stream
d) 150 bits per second serial data stream
e) 75 bits per second serial data stream

2.2.3 Diversity Provisions

Full dual diversity operation usable either as space or frequency diversity; combining is fully coherent, optimum matched filter weighted.

2.2.4 F-RAKE

A correlation measurement of the phase and amplitude characteristics of the transmission medium is provided at each subchannel frequency. This derived reference is used for fully coherent detection of received information. An adjustable measurement time constant is provided.

2.2.5 Frequency Averaged Reference

Provision is made to take advantage of frequency coherence across small portions of the transmission band by integrating reference measurements over three adjacent sub-channels.

2.2.6 Decision Feedback

Utilization of past data decisions is employed to improve smoothing of the derived detection reference.

2.2.7 AGC Provisions

Twenty db of automatic gain control is provided for each diversity signal.

2.2.8 Demodulation

An internal pseudo-random sequence generator identical to that at the transmitter is provided for proper signal demodulation.

2.2.9 Timing Reference

An internal timing source with stability of 1 part in 10^8 per day is provided.

2.2.10 Physical Size

Three six-foot relay rack cabinets plus power supply.

3.0 System Controls

3.1 Transmitter Control Panel

The data rate selection switch on the transmitter control panel provides the operator with the ability to select data rates of 1200, 750, 375, 150 and 75 bits per second. Second, fourth and eighth order coherent matched filter redundancy are automatically provided for the 375, 150 and 75 b/s transmission rates, respectively. The selection of lower data rates with increasing redundancy provides increasing immunity to degradations encountered over the communications link.

The transmitter control panel also contains a monitor selector switch which brings out the important test points to the associated output BNC connector. A sync output at 37½ cycles per second is also provided. In addition, this panel also contains fuses and indicator lights for filament transformers, fans, ovens, and a 30 volt DC power supply. Both operate and standby power switches are contained on this panel.

3.2 Transmitter Test Controls

In the transmitter terminal a row of toggle switches is mounted behind a narrow hinged panel above the power and data control panel. These switches are provided for test and troubleshooting purposes. The switches select the following functions:

1) I modulation: This is a 2-position switch providing either normal system operation or, in the second position, complete inhibition of the information component of the transmitted signal.

2) Test: This switch has two positions -- normal or test. In the test position, it enables the channel selector switches (see 5 below).

3) Function: This is a 2-position switch whereby a selected channel, or pair of channels, are either deleted from the spectrum or selected to be the only spectral components transmitted.

4) Guard Time: By means of this switch the operator may elect to transmit with the full 13.3 millisecond guard time or to simulate a reduced 6.7 millisecond guard time.

5) Channel Selector: The group of five switches, switches 5, 6, 7, 8 and 9, constitute the channel selector switches. Each switch controls a digit in a 5-bit binary word. By means of switch combinations, any channel of the

32 may be selected. This channel, depending on the function switch setting, will either be deleted or be the only channel transmitted.

6) The tenth switch modifies the channel selection function in that in one position a single channel is selected, whereas in the second position an adjacent pair of channels is transmitted.

3.3 <u>Receiver Control Panel</u>

The receiver control panel is located at the front of the center cabinet of the receiver terminal. It contains the following controls:

a) RAKE time constant: Four F-RAKE time constants may be selected at the discretion of the operator. The optimum time constant is a function of the turbulence of the transmission medium. Time constants of 1, 2, 4 and 8 frames (one frame is 26.7 milliseconds) may be selected. A small button adjacent to the RAKE time constant switch causes the RAKE memory to be frozen when depressed. This function is particularly useful for providing "snapshots" of instantaneous ionosphere bandpass characteristics for still photographs.

b) Data rate: A data rate selection switch identical to the data rate selection switch at the transmitter is provided.

c) Sequence sync lights: A pair of lights is provided to indicate when the receiver sequence is properly synchronized with the incoming signal. When synchronization has been achieved the light labelled "In" will glow green steadily without flickering. The light labelled "Out" glows red when the receiver is not synchronized. The two lights are completely complementary.

d) Manual sequence and framing synchronization: A switch which is labelled "Auto-Manual" permits the disabling of the automatic sequence synchronization function. When this switch is in the manual position, the alignment of the pseudo-random sequence is controlled manually by the sequence step switch located on this panel.

In addition, in the manual position the framing step switch is also activated. The automatic framing operation, however, is still operative. A switch for disabling the automatic framing control is found on Chassis A-29.

This 2-position switch is labelled "X" and "F". In the "F" position the automatic framing control is operative, while in the "X" position the system timing is locked to a stable timing reference rather than the framing control signal.

e) Guard time: A switch labelled "Guard Time" with two positions -- "In" and "Out" -- is provided on the main panel. During normal operation this switch is kept at the "In" position. In order to simulate the effects of operation without guard time, this switch may be slipped to the "Out" position. This causes a 6.7 millisecond shift in receiver timing. This new framing position will provide a good simulation of operation without guard time when a 13.3 millisecond guard time is employed at the transmitter. When the 6.7 millisecond guard time is transmitted, however, a no-guard time simulation is best set up by means of the manual framing switch.

f) Monitor selector: A monitor selector switch provides selection of waveforms at several test points in the two diversity parts of the system. These test points are routed to the two BNC outputs on the panel.

3.4 Additional Receiver Controls

3.4.1 Some additional function controls have been placed on a narrow panel immediately below the main control panel. Two switches are found there.

a) Post-decision feedback: The first switch labelled "PDF" is an on-off switch which permits the post-decision feedback function to be disabled. In normal operating conditions, this switch should be set to "ON".

b) A second switch labelled "All or EOP" (every other pilot) allows modification of the detection mode of the system. Every subchannel of the transmission contains both a signal and a pilot vector. However, in order that receiver operation simulate operation at 3,000 bits per second, it is necessary that the receiver ignore the known pilot vectors in every other channel. When this switch is in the "EOP" position, the transmission is treated as though pilots existed only in alternate channels. Thus for channels with pilots the detection reference depends on the pilot in that channel whereas for channels without pilots the detection reference will be the average of the pilots in the two adjacent channels. In the "All" position, all channels are normally treated to use the pilot vectors. It was originally envisioned that this switch should normally be in the "EOP" position and switched to the "All" position only for purposes of comparison to see if there was any evidence of degradation in the EOP mode. However, subsequent changes associated with the switches to be described next cause this switch to be thrown to the "All" position for normal operation.

c) A sync output at 37.5 cycles per second is provided on this panel.

3.4.2 Field Test Modification

In addition to the control switches previously described, three more switches were provided during the course of the field test. They are located on a small panel at the top front of the right-hand receiver cabinet. These switches are described as they appear from left to right on the panel.

a) Fast Frame: The framing control signal is applied to the oscillator from which all receiver timing is derived. The strength of this control signal is proportional to the degree of receiver misframing. Thus when signal is present, the receiver framing becomes locked to the framing of the incoming signal. In the absence of signal, however, it is best that the receiver timing be locked to the stable timing reference oscillator rather than to a noisy feedback signal. This will minimize the frame drift rate between transmitter and receiver when signal is absent. A relay for controlling the timing function has been added on Chassis A-29. This relay is actuated by the sequence synchronization indicator. This indicator directs the relay to select the stable timing reference when there is no sequence synchronization (and thus in all likelihood no signal). When synchronization is achieved the framing control signal is automatically applied to the timing oscillator.

Although the tracking properties of the automatic framing control are excellent, the pull-in rate from an initially poor framing point is very slow. In order that proper framing be achieved quickly after the acquisition of signal a fast framing feature was added. This fast framing feature may be either enabled or disabled by the first switch in the row. The fast frame mechanism is controlled by the normal framing signal. It is activated only when the normal framing voltage exceeds predetermined positive and negative thresholds thus indicating a large framing error. When these thresholds are exceeded, the fast framing causes quantized framing steps of approximately 400 microseconds such as would normally be derived from the manual framing control. When proper framing (within the predetermined limits) is achieved, the large framing steps are inhibited.

b) Pilot PDF: The second switch is labelled "Pilot PDF" (post decision feedback). This control should be turned on only when the switch described in the previous section (3.4.1.b) is set to "All". When this switch is activated, the reference for any given bit detection is derived from prior frames of the subchannel to be detected and the two neighboring frequency channels. However, those alternate channels or components of channels which are not to be treated as pilot vectors are detected as signal. Post decision feedback is applied to them in order that all signal and pilot components can contribute profitably to the integrated RAKE detection reference.

The third switch determines that either pilots always occur in the same frequency channel or that the pilots alternate from channel to channel in succeeding frames. The preferred mode of operation is to have pilots alternate from frequency to frequency on succeeding frames; i.e., to be interleaved in time and frequency.

3.4.3 Frequency Averaging of Reference

On the back of the main control panel is found a card socket which contains one card; a holder is present for two other cards. These cards are labelled "Average of 1", "Average of 3", and "Average of 5". The normal system operation is obtained when the "Average of 3" card is used. "Average of 1", "Average of 3" and "Average of 5" pertain to the number of adjacent channels averaged for a given channel detection reference. The "1" and "5" cards are provided for experimental purposes only.

3.4.4 Summary of Switch Positions for Normal Operation

In order to provide normal operation a summary of the proper switch positions for the additional control functions is here provided:

a) Post decision feedback (3.4.1.a) set on "On".
b) All-EOP (3.4.1.b) set to "All".
c) Fast frame (3.4.2a) set to "On".
d) Pilot PDF (3.4.2.b) set to "On".
e) Alternate-Not Alternate (3.4.2.b) set to "Alternate".
f) "Average of" card (3.4.2.c) insert "Average of 3" card.

4.0 Critical Subsystem and Component Specification

Specifications on critical subsystem and component areas are given in this section.

4.1 Fourier Transformer Memory Loop

4.1.2 Specifications for Ultrasonic Line

The following specifications give design specifications with tolerances permitted and min/max specifications. The delay line(s) are to be mounted in a double oven with proportional temperature control. The line(s) will be hermetically sealed and provided with BNC Input-Output Connectors.

	Detailed Specification	Design Specification	Tolerance	Min/Max Specification
1)	Mid-range delay time	421.878 usec	±0.05 usec	
2)	Carrier frequency, f_o	37 mcs	±0.5 mcs	
3)	Bandwidth (-3 db)	10 mcs		8 mcs min
4)	Spurious Responses			
	a) Sum of all spurious	> -50 db down		
	b) Third round	> -55 db down		>-50db down min
	c) Any 1 spurious	> -65 db down		
	d) Leakage	> -70 db down		>-65db down min
5)	Attenuation at f_o into 50Ω	< 55 db		60 db
6)	Transducer Capacitance	< 80 pf		100 pf max
7)	Delay Stability with prop. oven (long term)	0.1 usec/day (absolute)	±20%	
8)	Rate of change of Delay line	<0.7 nanosec/min	+10%	
9)	Ambient Temp. Range	0^oC to 65^oC		
10)	Max. Rate of Ambient Temp. Change	10^oC/hour		
11)	Transducer Loss Resistance Input + Output	1K ohms nominal		

4.1.2 Critical Coil and Transformer Specifications

Coils in both transmitter and receiver memory loops are identical. In order that the coils listed below may be identified, the receiver memory loop block schematic from the Instruction Manual, Book II, is included (Figure 1).

4.1.2.1 High Q Coil, L7 (Figure 1)

1) Shape - Toroid
2) Outside diameter - 1-7/8"
3) Core cross-section, square $\frac{1}{4}$"x$\frac{1}{4}$"
4) Ferramic, Q-2 material
5) 38 turns, No. 22 wire
6) L at 5.6 mc = 30 uh ±5%
7) Unloaded Q > 250

4.1.2.2 Memory Loop Coils

The following memory loop coils are wound on Cambion coil form type 1191. The appropriate core material for the intended frequency is used. Terminal layouts 3 and 5 apply.

a) Coil between V_2 and V_3 (Figure 1)

This is a step-down auto transformer having a 10 turn primary and 2 turn secondary of number 34 wire. Core position is adjustable; minimum and maximum values for the primary at 37 mc are listed below.

Min.: $L < 1.2$ uh, $R_p > 16$ k
Max.: $L > 2.2$ uh, $R_p > 60$ k

b) Double tuned transformer drive by V_9, V_{10} (Transformer No. 100)

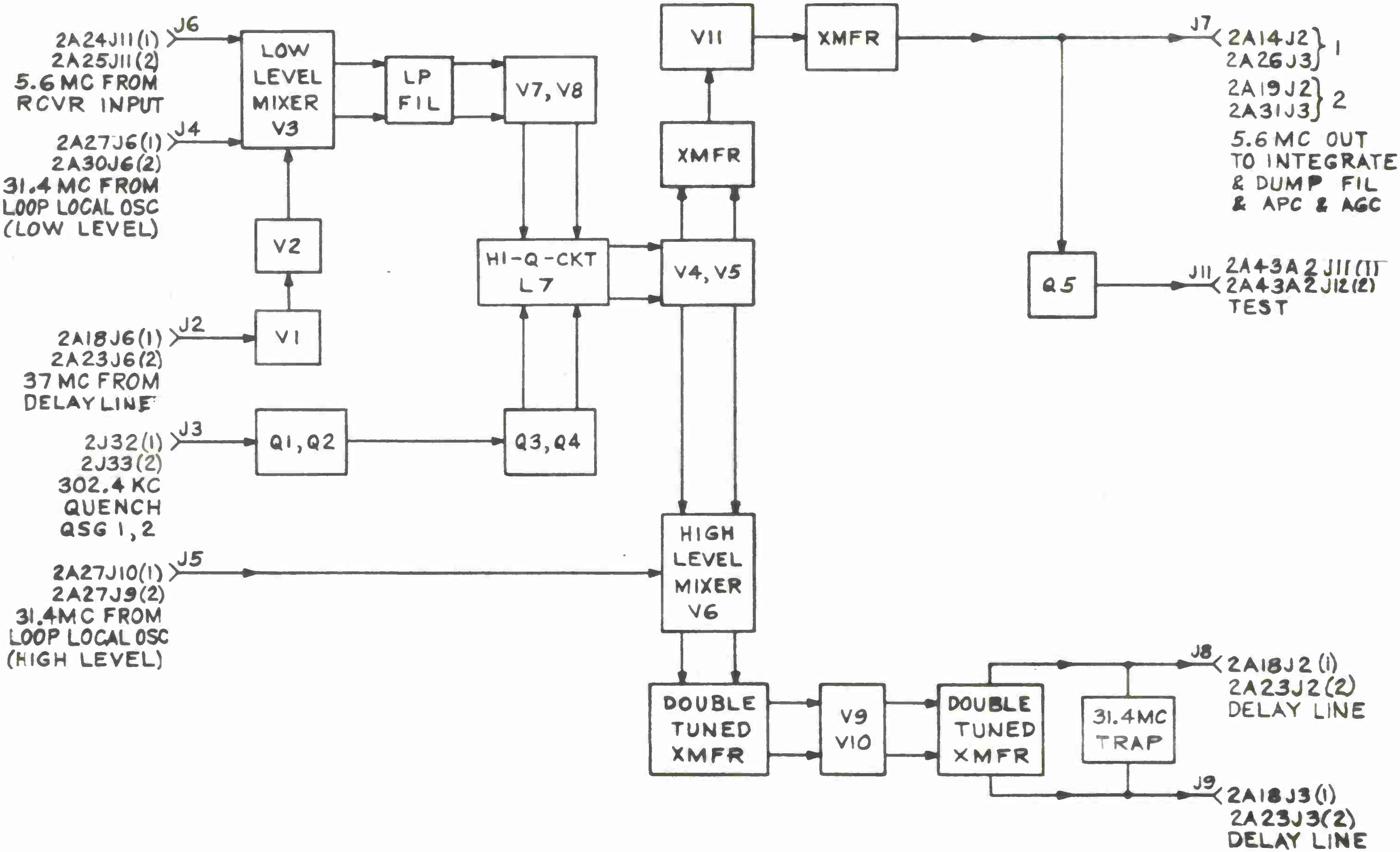
Mechanical data is given in Figure 2. The following electrical specifications at 37 mc apply.

Coefficient of coupling: $23\% < k < 28\%$

Terminals 1-3	$L = 1.73$ uh ±3%
	$R_p > 60$ k
Terminals 4-6	$L = 1.73$ uh ±3%
	$R_p > 30$ k
Terminals 1-2	$L = 1.20$ uh ±3%
2-3	$R_p > 13.5$ k

c) Double tuned transformer drive by V_6 (Transformer No. 200)

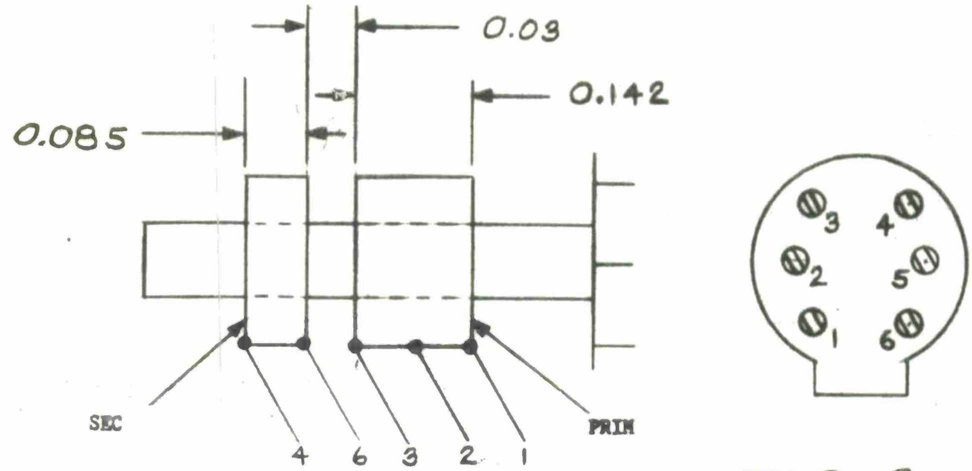
Mechanical data is given in Figure 3. The following electrical specifications at 37 mc apply.



SCHEM D10550 }
ASSY 2A17 } 1

SCHEM D10612 }
ASSY 2A22 } 2

FIGURE 1
RCVR MEMORY LOOP 1 & 2



XFMR NO. 100

FIG. 2

	IND (μh)	NO. TURNS/WIRE SIZE (AWG)		FREQ (mc)	K (%)	GAC PART NO.
PRIM	3.5	20 CT	36	37	23	51072-1
SEC	1.75	13	36			

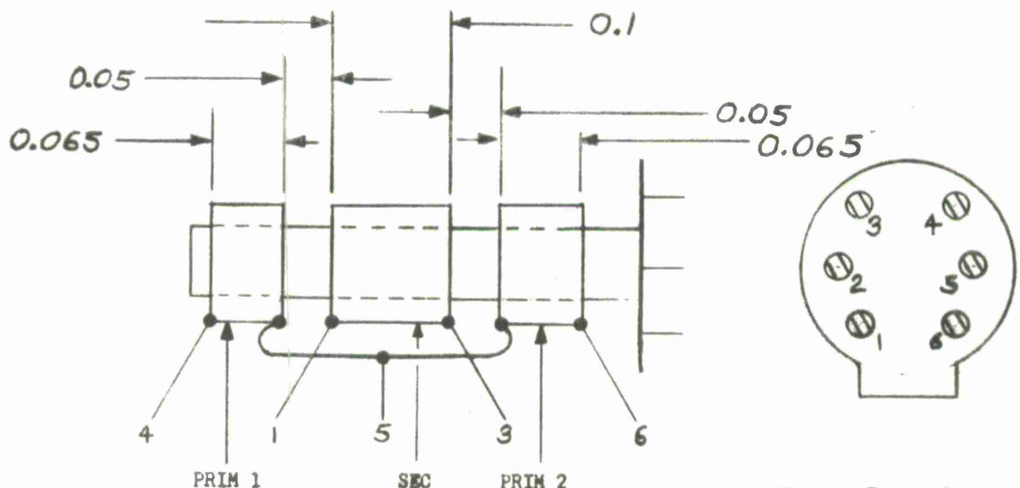


FIG. 3

XFMR NO. 200

	IND (μh)	NO. TURNS/WIRE SIZE (AWG)		FREQ (mc)	K (%)	GAC PART NO.
PRIM 1	1.45	11	36	37	33	51072-2
PRIM 2	1.45	11	36			
SEC	2.70	17	36			

NOTES: (Both Xfmrs)

1. Coil form is Cambridge Thermionic part No. 1191-3 (tuning slug removed)
2. Windings are single layer and uniformly spaced over assigned dimension.
3. All wire used has heavy Formvar insulation.
4. All windings are doped with polystyrene Q-dope (General Cement No. 37-2).

Coefficient of coupling:	32% < k < 36%
Terminals 4-6	L = 3.0 uh ±5%
	R_p > 50 k
Terminals 1-3	L = 2.7 uh ±5%
	R_p > 50 k
Terminals 4-5	L = 1.42 uh ±5%
5-6	R_p > 23 k

d) Delay line output transformer (Transformer No. 400)

Mechanical data is given in Figure 5. The following electrical specifications at 37 mc apply.

Coefficient of coupling:	23% < k < 28%
Terminals 1-2	L = 1 uh ±3%
	R_p > 22 k
Terminals 3-4	L = 0.183 uh ±3%
	R_p > 2.4 k

e) Delay line input transformer (Transformer No. 400)

Mechanical data is given in Figure 4. The following electrical specifications at 37 mc apply.

Coefficient of coupling:	32.5% < k < 34%
Terminals 4-6	L = 3.6 uh ±3%
	R_p > 70 k
Terminals 1-3	L = 0.26 uh ±3%
	R_p > 3.4 k
Terminals 4-5	L = 1.65 uh ±3%
5-6	R_p > 30 k

4.2 Fourier Transformer Output Sampling Filters

4.2.1 Specification for High Q Integrating Coil, Q Multiplier Circuit

Burnell Type TC - 17 coil
l = 1.0 MHY at 151 kc
Q > 200 at 151 kc
Temperature compensated and shielded

4.2.2 Output Sampling Filters, Critical Alignment Procedure

1) Input Signal Gate Balance

Connect the input gating signal as an input to the buffer driving the Q multiplier. Have the dump and readout commands connected to the A filter. First tune all output amplifiers to 151.2 kcs. Then observe input gate balance at

XFMR NO. 300

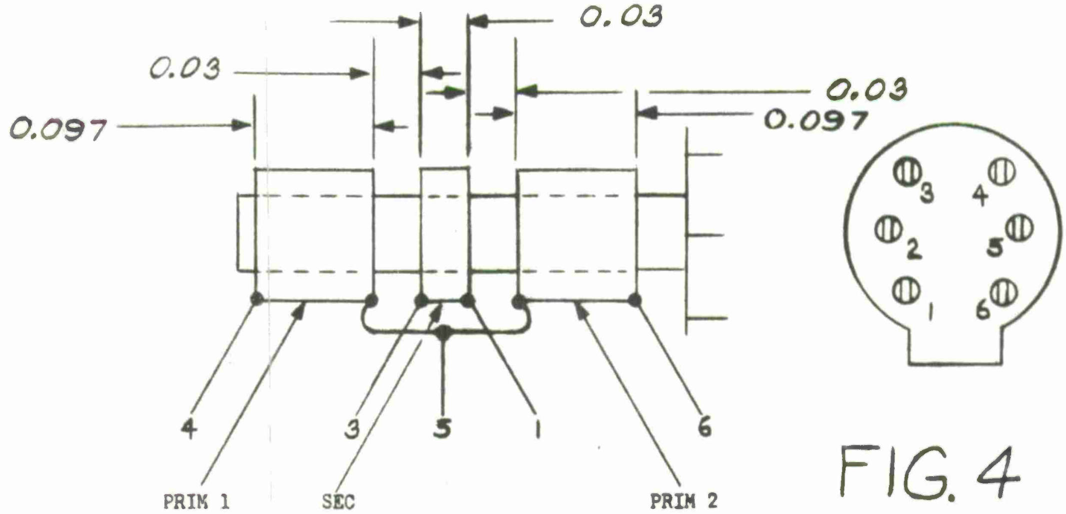


FIG. 4

	IND (µh)	NO. TURNS/WIRE SIZE (AWG)		FREQ (mc)	K (%)	GAC PART NO.
PRIM 1	1.65	12½	34	37	33	51073-3
PRIM 2	1.65	12½	34			
SEC	0.26	3½	34			

XFMR NO. 400

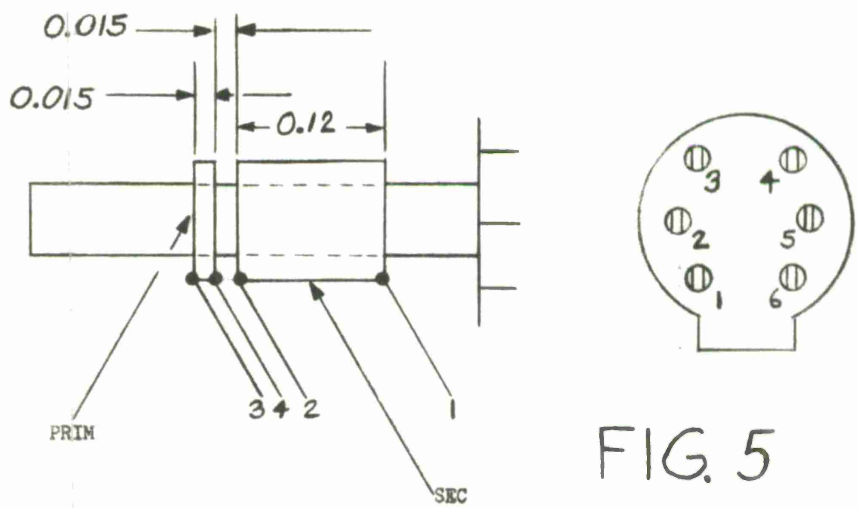


FIG. 5

	IND (µh)	NO. TURNS/WIRE SIZE (AWG)		FREQ (mc)	K (%)	GAC PART NO.
PRIM	0.18	3	30	37	23	51073-4
SEC	1.0	12	30			

NOTES: (Both Xfmrs)

1. Coil form is Cambridge Thermionic part No. 1191-3 (tuning slug removed).
2. Windings are single layer and uniformly spaced over assigned dimension.
3. All wire used has heavy Formvar insulation.
4. All windings are doped with polystyrene Q-dope (General Cement No. 37-2).

the final output and minimize output signal by neutralizing the input gate.

2) Coarse Adjustment of Q Multiplier (Qx)

Using the input gating waveform as above, observe the signal just ahead of the read-out gate and adjust Q for flat ring out and tune Qx for best linearity of integration.

3) Fine Adjustment of Q Multiplier

Feed 5.6 mcs into input terminal of the integrate-and-dump filter and align the first amplifier. Disconnect the 90° (quadrature) 5.6 mcs phase reference and connect the 0° (in-phase) 5.6 mcs phase reference to the in-phase phase detector. Observe the signal at the pre-filter output when the input gating signal is returned to the read-in gate. Adjust the input frequency to observe a 1 envelope cycle during the gating interval at the pre-filter output. Now adjust the input frequency very slightly from the above reference point so as to observe a slow drift rate in the pre-filter output. Observe with scope at the final output (after the read-out gate) and adjust the Qx frequency to minimize any amplitude breathing at the final output.

4) Phase Reference Adjustment

For approximate phase adjustment set the output amplitudes of 0° and 90° to be equal on a dual beam scope. Switch to algebraic addition and observe whether the sum is $\sqrt{2}$ times the individual reference size. Adjust phase controls if necessary to meet this condition.

For fine adjustment, feed 5.6 mcs into the input terminal of the integrate-and-dump filter. Connect the 0° phase reference to the in-phase phase detector. Observe the final output after the read-out gate and vary the input frequency of signal generator to maximize the output signal. We expect to see some breathing in the output. Then insert the 90° 5.6 mcs quadrature reference and then adjust the gain of the in-phase signal against the phase of the 90° reference to observe a minimum of breathing at the final output. There should be a flat output for all input frequencies with no breathing in the output if the amplitude and phase adjustment is proper.

5) Dynamic Range and Single Tone Measurement of Filter

At this point measure the peak-to-null ratio as a function of input signal level at the grid of the first input stage to determine the dynamic range of the Qx.

6) Repeat steps 1-5 for B filter.

7) Amplitude and Phase Equalization of A and B Filter
Adjust A and B output amplitudes to be equal. Then adjust phasing of A reference pairs relative to B reference pairs to reduce scallops after bandpass filtering by observing at 455 kc output point in the transmitter output converter chassis. This finishes the alignment of one complete filter.

Note that at the receiver the above adjustment is made by observing at the synchronous demodulator outputs.

4.3 Timing Reference

The listed specifications apply to the JKTO-43 Crystal Oscillator used as the master timing reference in both transmitter and receiver.

a) Frequency: 1.934400 mc
b) Stability: better than 5×10^{-9} parts/day for room ambient variation $\pm 2.5^{o}C$
c) Oven power to turn on 0.75 amp
d) Oven power normal operation 0.25 amp
e) Oven to operate at $75^{o}C$ with room ambient $0^{o}C$ to $65^{o}C$
f) 1.934400 mcs to be centered on trim range of ± 70 parts/10^8.
g) Output 1 v rms into 5 k ohms
h) Stability over ambient range of 0^{o} to $65^{o}C$ better than 5 parts in 10^8.

4.4 Memory Loop Oscillators

The oscillators at 31.400000 mc and 31.404725 mc are parts of a critical subassembly. The specifications on both the crystals and ovens used are given below.

4.4.1 Ovens

HOTO-P3 ovens with crystals matched in pairs shall provide absolute stability of 1 part in 10^7 per day and differential stability of 3 parts in 10^8 per day. Any cycling effects must be within the above noted stability. Heater power 115 v AC at 60 cps. Transients of oven switching to be 60 db down at crystal output pins.

4.4.2 Crystals

Crystals are paired for thermal tracking with f_1 = 31.400000 mcs and f_2 = 31.404725 mcs to operate in HOTO-P3 oven with differential stability of 3 parts in 10^8 per day and absolute stability of 1 part in 10^7 per day. Holder type HC6/U, padding capacitance = 32 pf.

5.0 Laboratory Evaluation

The system was tested in a laboratory environment. The data presented here represent test results from a testing period consisting of 18 and 19 February 1964. The block diagram of Figure 6 applies in all cases where error rate measurements were made. The system was tested in the presence of additive Gaussian noise and with static multipath up to 3.33 milliseconds. Two multipath combiners working in conjunction with the General Atronics HF Ionospheric Simulator provided a simulation of two diversity inputs to the receiver.

5.1 Performance in Additive Gaussian Noise

The results of laboratory tests with additive Gaussian noise are listed below. A graph comparing experimental to theoretical performance at 750 bits/second is given in Figure 7.

a) Nonredundant Performance in Additive Gaussian Noise

Conditions: Time Constant 0.85 second
Data Rate 750 b/s
Guard Time 6.7 ms
Every other pilot operating mode

S/N	ERRORS	TIME	MEAN ERROR RATE
+5 db	723	30 sec	3.28×10^{-2}
	753	30 sec	
+7 db	242	30 sec	1.19×10^{-2}
	279	30 sec	
	280	30 sec	
+10 db	43	60 sec	1.34×10^{-3}
	37	60 sec	
	66	60 sec	
	144	120 sec	
	72	60 sec	
+12 db	59	10 min	1.29×10^{-4}
	57	10 min	
+14 db	4	10 min	8.9×10^{-6}
+16 db	1	119 min	1.85×10^{-7}

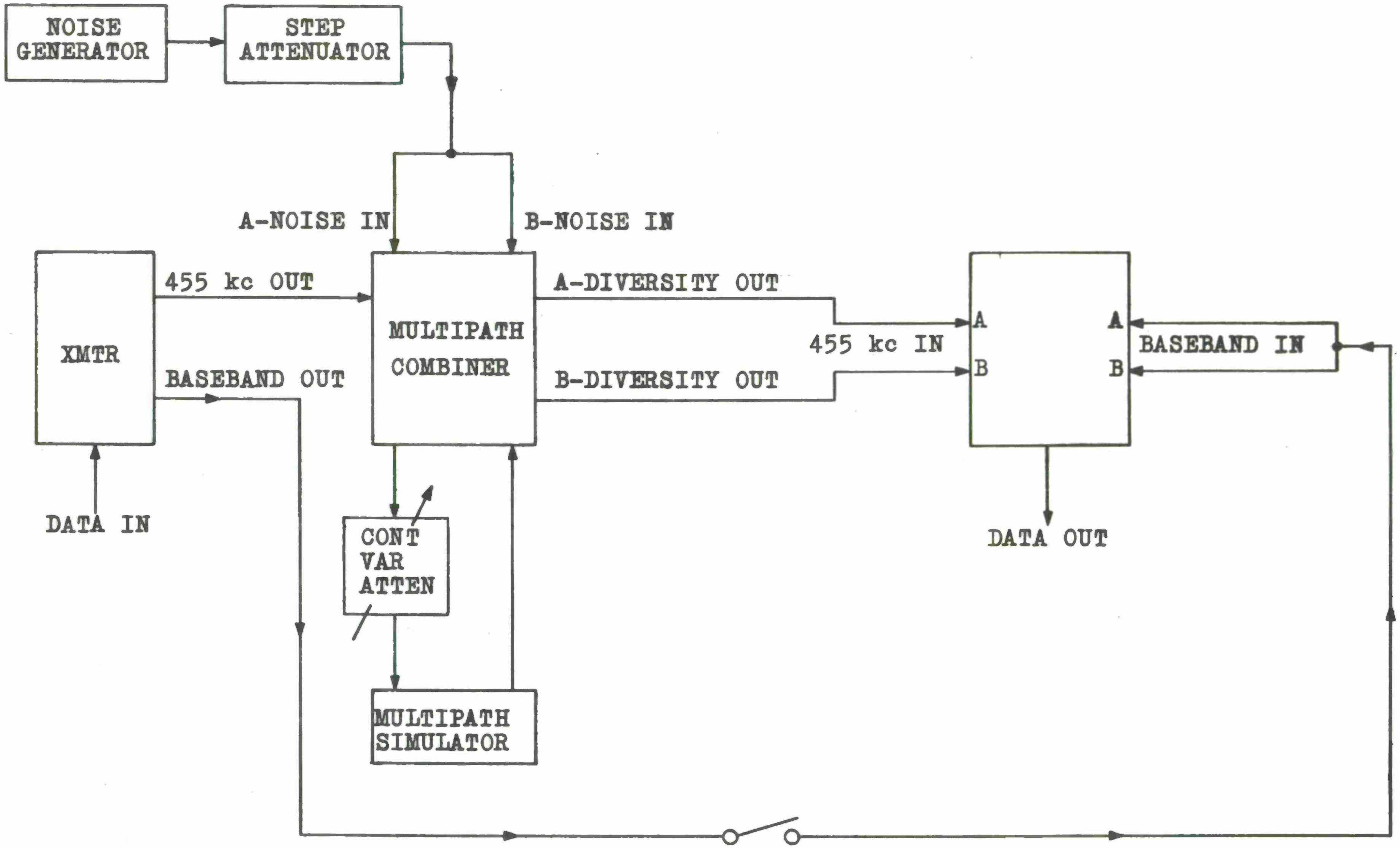
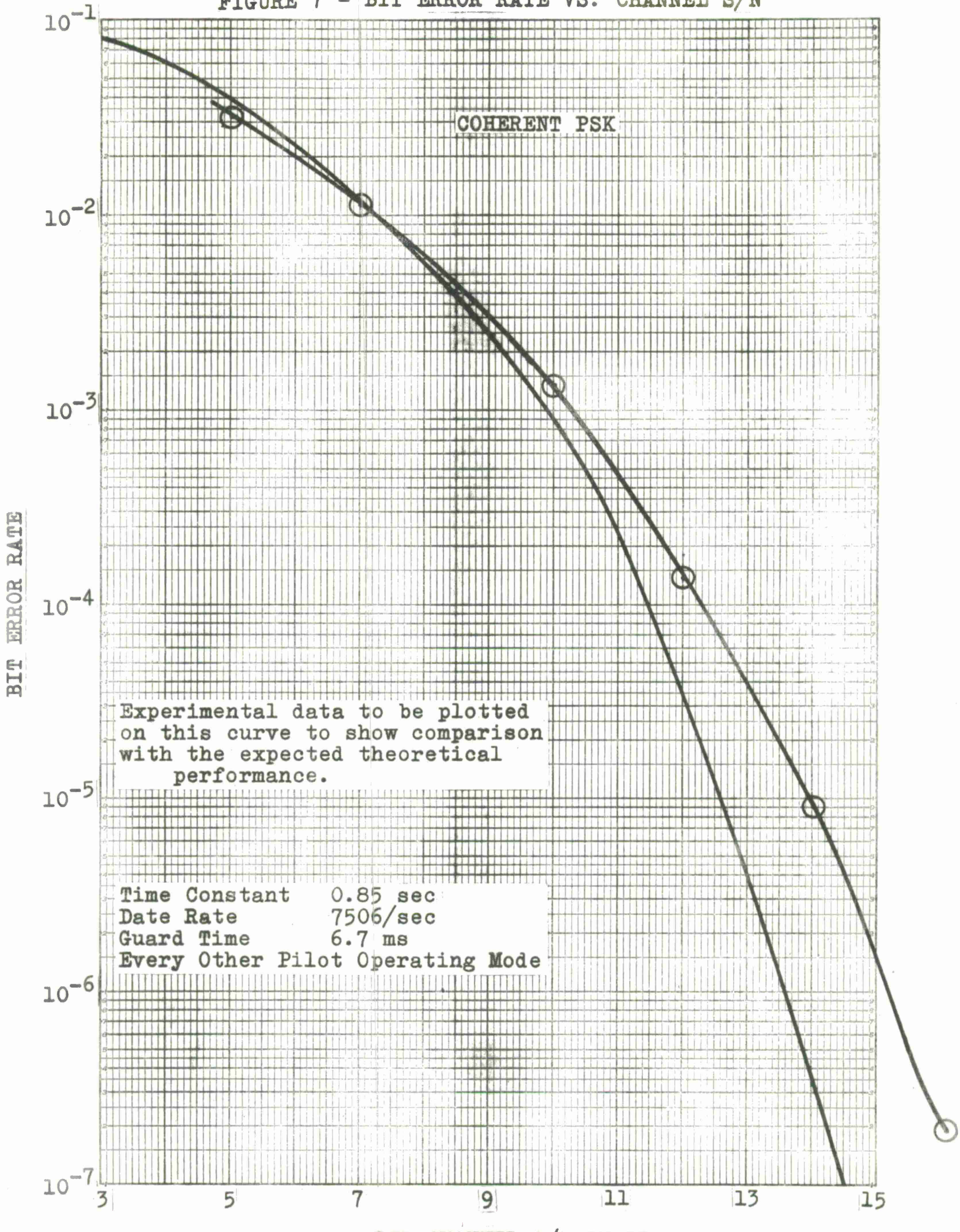


FIGURE 6 - BLOCK DIAGRAM OF TEST SETUP

FIGURE 7 - BIT ERROR RATE VS. CHANNEL S/N



b) Redundant Performance in Additive Gaussian Noise

Conditions: Time Constant 0.85 sec
Data Rate Variable
Guard Time 6.7 ms
Every other pilot operating mode
S/N Ratio 0 db

DATA RATE	REDUNDANCY	ERRORS	TIME	ERROR RATE
375 b/s	2/1	626	30 sec	5.6×10^{-2}
150 b/s	5/1	87	1 min	9.6×10^{-3}
75 b/s	10/1	8	3 min	5.9×10^{-4}

5.2 Performance in Simulated Multipath and Fading

Conditions: Bit Rate 750
Time Constant 0.85 sec
Multipath 3.333 milliseconds
6.6 milliseconds Guard Band
Every other pilot
Five fades in band
Direct path and 3.333 millisecond path of equal strength

S/N	REDUNDANCY	ERRORS	TIME	ERROR RATE
+25 db	1	3	60 min	1.1×10^{-6}
+10 db	1	52	30 sec	2.2×10^{-3}
+10 db	1	110	60 sec	2.44×10^{-3}
(Cabinet was banged and phasing slightly off in P- and I- coming into final demodulator.)				
+10 db	1	39	60 sec	0.87×10^{-3}

5.3 Residual Crosstalk Measurement

The crosstalk of a fully loaded back-to-back pair of transmitter and receiver Fourier transformers was measured. Only one of the receiver Fourier transformers was used for this demonstration. This measurement was made by dropping out a single input channel and measuring the noise in the unloaded channel as compared to the loaded channel output. This test was performed for two edge channels and a center channel. The measurement was made while the system was carrying information at 750 bits per second (less the capacity of the dropped channel).

An oscilloscope was used to display the output of the receiver Fourier transformer. Reference level was established with all channels on, then a center or edge channel dropped out at the transmitter and the residual crosstalk measured.

This test also served as a measurement of the system dynamic range.

a) Center Channel

Observer B.U. 10 to 1 {15 divisions LOADED channel / 1.5 divisions UNLOADED channel
(No. 16 channel)

Observer R.T. 6 to 1 {15 divisions LOADED channel / 2.5 divisions UNLOADED channel

Observer B.G. 7 to 1 {14 divisions LOADED channel / 2.0 divisions UNLOADED channel

Observer A.H. 7 to 1 {14 divisions LOADED channel / 2.0 divisions UNLOADED channel

Mean ratio 7.5/1 = 17.5 db

b) Channel 1

Observer R.T. 5 to 1 {12.5 divisions LOADED channel / 2.5 divisions UNLOADED channel

Observer B.G. 6.5 to 1 {13 divisions LOADED channel / 2 divisions UNLOADED channel

Observer A.H. 6.5 to 1 {13 divisions LOADED channel / 2 divisions UNLOADED channel

Observer B.U. 7.5 to 1 {15 divisions LOADED channel / 2 divisions UNLOADED channel

Mean ratio 6.4/1 = 16.0 db

c) Channel 32

Observer R.T. 5 to 1 {12.5 divisions LOADED channel / 2.5 divisions UNLOADED channel

Observer B.G. 4.3 to 1 {13 divisions LOADED channel / 3 divisions UNLOADED channel

Observer A.H. 5.6 to 1 {14 divisions LOADED channel / 2.5 divisions UNLOADED channel

Observer B.U. 6 to 1 (15 divisions LOADED channel
(2.5 divisions UNLOADED channel

Mean ratio 5.2/1 = 14.3 db

5.4 Primary Power Variation

The effects of varying the primary supply voltage ±5% from the nominal value of 115v are demonstrated while the system is operating back-to-back (transmitter connected to receiver) on a nonfading path.

Conditions:		
	Data Rate	750 bits/sec
	Time Constant	0.85 sec
	Guard Time	6.6 milliseconds
	Every other pilot	
	Signal-to-Noise	+13 db
	Redundancy	1

LINE VOLTAGE	TIME	ERRORS	ERROR RATE
105 V	120 sec	153	1.7×10^{-3}
109 V	300 sec	19	0.85×10^{-4}
115 V	300 sec	8	3.55×10^{-5}
121 V	300 sec	50	2.22×10^{-4}
125 V	60 sec	57	1.27×10^{-3}

5.5 2/18/64 - 2/19/64 Overnight Error Run

Conditions:		
	Data Rate	750 bits/sec
	S/N Ratio	+15 db
	Time Constant	0.85 sec
	Guard Time	6.6 milliseconds
	All pilots	

	ERRORS	TIME	ERROR RATE	CORRECTED ERROR RATE
Start 5:30 P.M. Stop 9:30 A.M.	238(138)	16 hrs	5.5×10^{-6}	3.2×10^{-6}

In subsequent tests the counter used (HP5243L) persistently skipped the odd hundreds (from 99 - next count 200). Assuming this happended during the 16 hour test, gives the corrected error count of 138 above.

5.6 Miscellaneous Measurements

5.6.1 Transmitter Output Level

Baseband output level is 0 dbm with 600 ohm termination. 0 dbm output is 0.375 V rms at each side of 600 ohm line to ground.

Range of available output of one side: 50 millivolt rms to 1.25 volt rms.

5.6.2 Receiver Input Level

Feed 0 dbm from transmitter directly to receiver (one side from transmitter output to one side of receiver input).

Receiver fully driven with input gain control set at one-quarter of full rotation.

A level of 0.375 V rms into one side of 600 ohm input of receiver represents a level of 0. 19 V rms into 600 ohm balanced input of receiver.

5.6.3 Automatic Sequence Synchronization Under Heavy Noise

Conditions:

Data Rate	750 bits/sec
Time Constant	0.11 sec
Redundancy	1
Signal-to-Noise	-6 db

Sequence synchronization manually retarded one step, then switched to automatic. After 62 steps (about 65 seconds) sequence synchronization automatically obtained.

5.6.4 Error Test with Transmitter at Data Rate 1200 bits/sec and Receiver at 750 bits/sec

Conditions:

Signal-to-Noise	+13 db
Time Constant	0.11 sec
Guard Time	6.6 milliseconds
All Pilots	

TIME	RECEIVER BIT RATE	TRANSMITTER BIT RATE	ERRORS	ERROR RATE
300 sec	750	750	49	2.18×10^{-4}
300 sec	750	1200	49	2.04×10^{-4}

Fast time constant of 0.11 has same effect as dropping S/N ratio by 1.2 db.

5.6.5 Transmitter-Receiver Digital Interfaces

The word output at the receiver is at the proper level of 0 volts and -20 volts when the transmitter input signal is at 0 volts for a space and anywhere from -1.5 volts to -24 volts for a mark. To reliably prevent false triggering from noise peaks, the maximum transmitter input for mark will be decreased to -5.0 volts.

5.6.6 Multipath Crosstalk Test with Guard Time

Conditions:	Data Rate	1200 bits/sec
	Time Constant	0.85 sec
	All Pilots	
	Multipath	3.3 milliseconds
	Guard Time	6.7 milliseconds

Multipath set for a 20 db attenuation of every 4th channel (1, 5, 9, 13, etc.). Under this condition, channel 16 has normal amplitude and channel 17 is 20 db down.

Channels 16 and 17 deleted in transmitter.

Crosstalk residue in receiver output shows no difference in channels 16 or 17.

Estimated residue ratio 6:1 (L.H.)
Estimated residue ratio 7:1 (R.G.)

Channels 2 and 3 deleted in transmitter. No change in crosstalk level, same estimates.

Multipath delay slowly varied from minimum to maximum, no change in crosstalk observed.

5.6.7 Miscellaneous Error Runs

Conditions:	Signal-to-Noise Ratio	+13 db
	Time Constant	0.85 sec
	Guard Band	6.6 milliseconds
	All Pilots	
	Redundancy	1
	No Multipath	
	Xmtr-Rcvr connected through 455 kc path	

DATA RATE	TIME	ERRORS	ERROR RATE
1200 b/s	300 sec	15	4.7×10^{-5}
750	300	7	3.1×10^{-5}
1200	600	31	4.3×10^{-5}
1200	900	49	4.5×10^{-5}
1200	1080	61	4.7×10^{-5}
1200	300	14	3.9×10^{-5}

Same conditions except: Signal-to-noise ratio > 25 db
Xmtr-Rcvr connected thru baseband path

DATA RATE	TIME	ERRORS	ERROR RATE
1200 b/s	30 min	0	-
1200	43 min	0	-

Error check between all pilots and alternate pilot conditions.

Conditions:		
	Signal-to-noise ratio	+13 db
	Time constant	0.85 sec
	Guard band	6.6 milliseconds
	Redundancy	1
	Xmtr-Rcvr connected through 455 kc path	

DATA RATE	PILOT	TIME	ERRORS	ERROR RATE
750 b/s	All	300 sec	5	2.22×10^{-5}
750 b/s	Alternate	420 sec	4	1.28×10^{-5}

6.0 Fourier Transformation of F-RAKE Output

6.1 Description of Technique

The S-3000X system provides, in the course of normal operation, a smoothed F-RAKE display which represents the bandpass spectral response of the transmission medium. This frequency response display is derived as an average over a number of frames of transmission. Thus, even in the presence of large amounts of noise, the F-RAKE display is still relatively noiseless.

It has long been realized that the Fourier transform of this display will be the impulse response of the transmission medium in the time domain. The output of the "A" Diversity Channel (see block diagram, Figure 8) is cabled directly to the input of "B" Fourier transformer. The output of "B" Fourier transformer displays the time impulse response of the transmission path.

6.2 Experimental Results

For the display of Figure 9, the General Atronics multipath simulator was set up to provide a direct path and a path delayed by 3.33 milliseconds of approximately equal strength. The spectral response is shown in line 1, and the time impulse response, line 2. The horizontal scale is marked off electronically and each burst (about 3½ per cm) corresponds to 417 microseconds. The bandwidth is 3 kc and TW product = 32.

The time resolution and dynamic range of the S-3000X double transform display compare favorably to the display of Figure 10. These oscillograms show the impulse response on a short range HF link at 3.01 mc.* A 10 kc time RAKE was used for this measurement.

With appropriate modifications both the phase as well as the amplitude of each discrete path may be measured.

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*Lightfoot, F.M. and Belenski, J.D., "The Use of Pulse Compression in Multipath Measurements". The Boeing Company, Ninth National Communications Symposium, October 1963, Utica, New York.

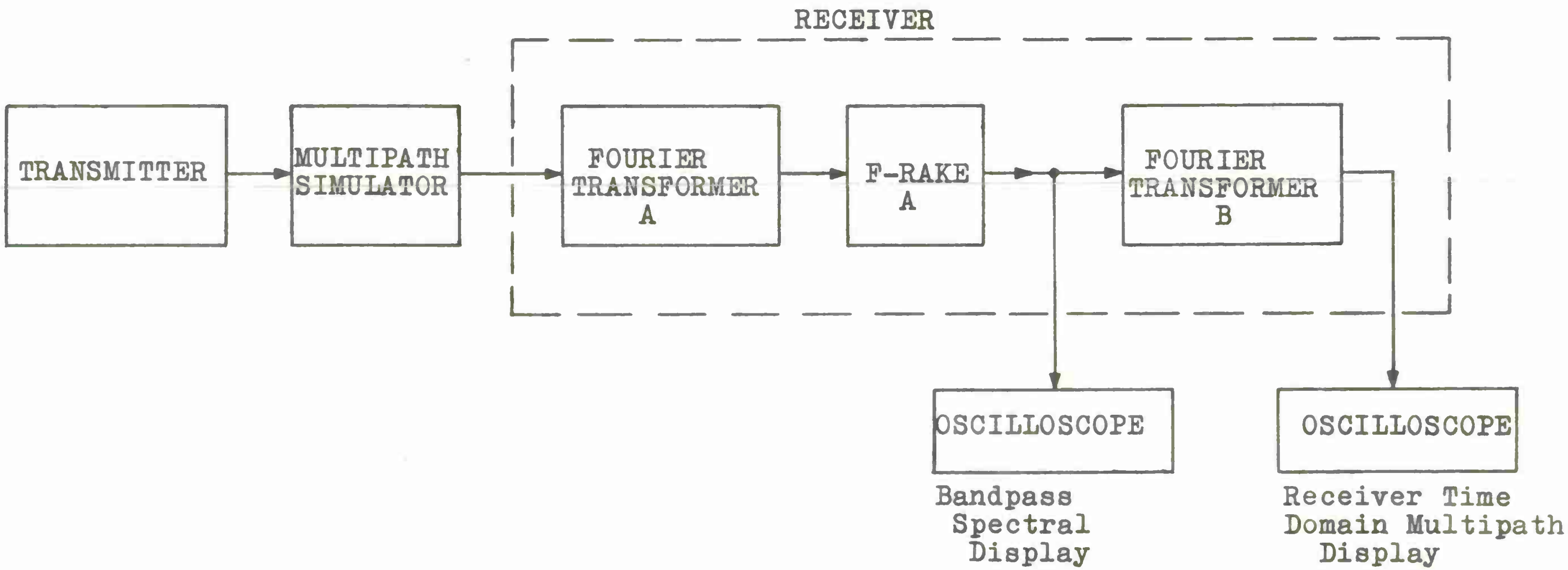


FIGURE 8 - THE S-3000X MODEM AS A PROBE YIELDING THE IMPULSE RESPONSE OF TRANSMISSION MEDIUM IN THE TIME DOMAIN

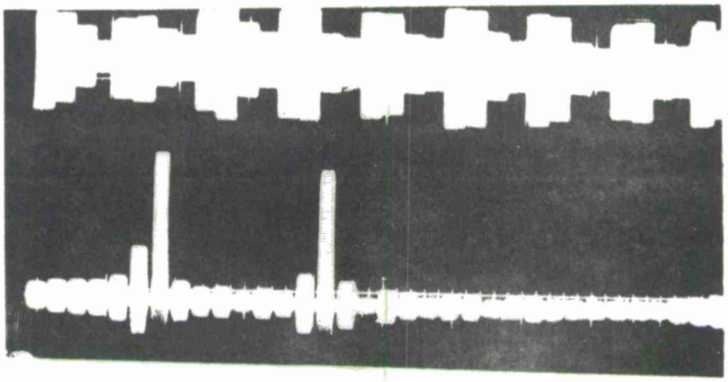


FIGURE 9 - FREQUENCY AND IMPULSE RESPONSE OF HF LINK SIMULATOR MEASURED BY S-3000X MODEM AS AN HF SOUNDER

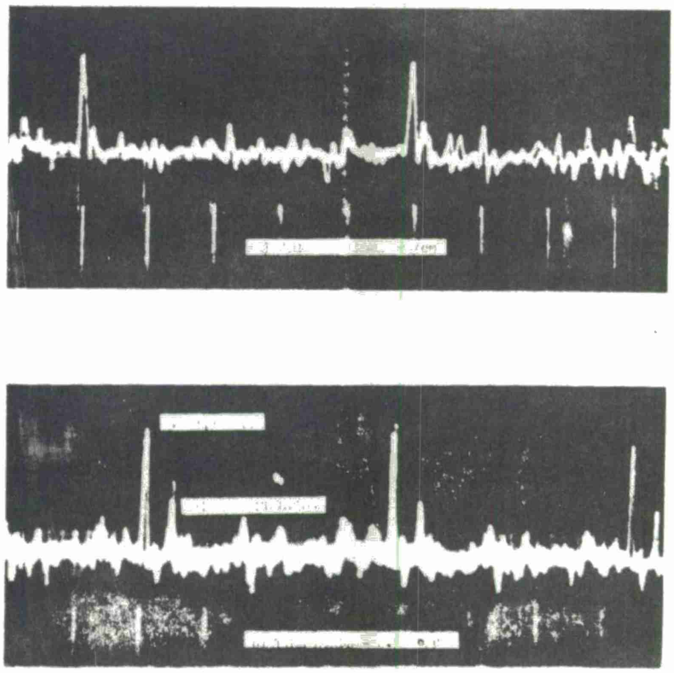


FIGURE 10 - IMPULSE RESPONSE OF 40 MILE HF LINK MEASURED BY 10 kc TIME RAKE

Precise path differences (to within a few microseconds) may be measured by slewing the receiver, in time, in calibrated amounts so that each path may be adjusted, in sequence to fall exactly on a quantized time position. The amount of analog time slew will be added to or subtracted from the final quantized position depending upon the direction of the slewing. The calibrated slewing may also be accomplished as a calibrated frequency change on the output of the F-RAKE.

7.0 Error Analysis

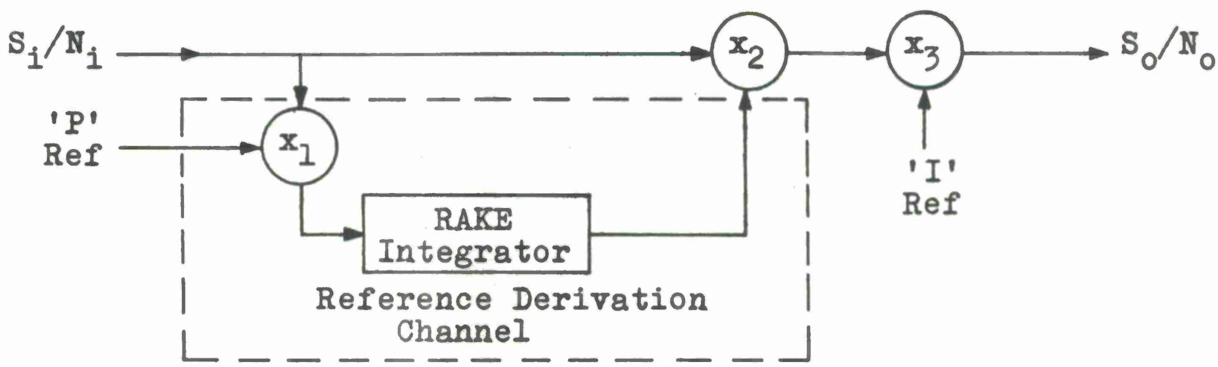
7.1 Comparative Performance of the S-3000X Detection Mechanism and DCPSK

The S-3000X is a variable data rate digital communications system designed for use with HF transmission. It permits a gradual trade-off between data rate and redundancy so as to optimize performance over a wide range of operating conditions.

This analysis derives the performance of the S-3000X Detection Mechanism in additive random noise in terms of the maximum data rate at which a usefully low error probability is maintained. The effect of fading is considered insofar as it limits the integration time which may be used to derive the coherent detection reference. The result is a family of curves showing the amount of redundancy required as a function of input signal-to-noise ratio.

Detector performance is compared with that of differentially coherent PSK. In the analysis DC PSK is permitted the use of redundancy; i.e., multiple channels, to overcome noise, so as to provide a common basis for comparison with the S-3000X. The combining of the multiple DCPSK channel outputs is assumed to take place prior to decision-making so as not to penalize the performance by mark-space decisions based on low S/N outputs. It is shown that the S-3000X system concept offers a significant data rate advantage over a differentially coherent system at low input signal-to-noise ratios. This improvement is the result of the RAKE detection process whose performance approaches that of the ideal correlation detector.

The basic detector is shown below.



In actual operation, this circuit serves all channels on a time-multiplexed basis. Conceptually the operation may be considered as a single channel, with the RAKE comb filter integrator replaced by its single-channel functional equivalent, a simple narrowband integrating circuit.

The signal input to the detection circuits consists of two quadrature components, one of which is used for information transmission, the other as a transmitted reference. Each of these components is phase modulated $\pm 180^{\circ}$ by an independent pseudo-random sequence.

The initial step in the reference derivation is the multiplication of the received signal by the local synchronized 'P' or pilot reference sequence. This multiplication in X_1 converts the pilot sequence to a coherent waveform which will be integrated in the RAKE integrator. Both externally added noise and the information modulated quadrature 'I' sequence appear as noise after X_1. Since reference and signal energies are equal the reference-to-total-noise ratio after X_1 is

$$\left.\frac{R}{N}\right|_{X_1} = \frac{S}{N_i+S}$$

The reference-to-noise improvement in the RAKE integrator is equal to the effective number of samples which are integrated which is limited by the ionosphere stability time. If the stability time constant is τ seconds and the sampling rate for each channel is W/sec., the maximum available integration improvement is $W\tau$. A typical channel rate is W=100 samples per second. Following integration, therefore, the reference-to-noise ratio is

$$R/N_R = 100\tau \frac{S}{S+N_i} \tag{1}$$

The final multiplier X_3 performs the function of synchronous detection by means of the 'I' sequence. Since this is a noise-free reference, this operation conceptually could be performed after the RAKE integrator without affecting system operation. The multiplier X_2 then may be considered as the final correlation detector. Both signal and reference inputs to this correlator are noisy, with the ratio of signal to accompanying noise being S_i/N_i and the ratio of reference-to-reference noise being given by Equation (1).

The signal-to-noise ratio existing at the output of a correlation detector with a noisy signal and noisy reference has been derived, and, for an uncoded waveform (TW = 1), is given by:

$$\frac{S_o}{N_o} = 2\,\frac{S_i}{N_i}\,\frac{1}{1 + \frac{N_R}{R}} \tag{2}$$

The reference-to-noise ratio R/N_R has been derived in terms of the input signal-to-noise ratio and is given by Equation (1). Substituting (1) in (2), the output signal-to-noise ratio becomes

$$\frac{S_o}{N_o} = 2\,\frac{S_i}{N_i}\,\frac{1}{1 + \left(\frac{1+N_i/S_i}{100\tau}\right)} \tag{3}$$

The factor $\dfrac{1}{1 + \left(\frac{N_i/S_i+1}{100\tau}\right)}$ is the degradation from the performance of an ideal coherent detector caused by the noise accompanying the reference input. It may be seen that this factor approaches unity as the input signal-to-noise ratio S_i/N_i becomes large and as 100τ, which is the number of samples over which the reference is smoothed, becomes large.

The signal output, S, of the detector is the square of the mean value of its output while the noise output, N, represents a dispersion of output levels about the mean. The noise output of the detector N_o is the variance of the output about the mean value. Where the noise is characterized by a normal or Gaussian probability density function, the probability of a bit error P_e is uniquely related to the output signal-to-noise ratio and is given by the probability distribution function

$$P_e = P(x<0) = \frac{1}{\sqrt{2\pi N}} \int_{-\infty}^{0} \exp -\tfrac{1}{2}\left(\frac{x-S^{\frac{1}{2}}}{N^{\frac{1}{2}}}\right)^2 dx \tag{4}$$

A useful bit error probability is 10^{-4}. The corresponding S_o/N_o may be found in tables of the probability distribution function to be 13.7 (ratio).

The S-3000X variable data rate facility allows the coherent combining of independent channel outputs to provide redundancy as required. For example, when the signal-to-noise output ratio for any one channel as given by Equation (3) falls below a usable level (such as 13.7), the outputs of r channels are combined in order to restore the desired output signal-to-noise ratio. In this combining process, the signal means add and the variances add, providing a combined signal-to-noise ratio which is related to the single channel signal-to-noise ratio by:

$$\left.\frac{S}{N}\right|_r = \frac{(rS_1^{\frac{1}{2}})^2}{rN_1} = \frac{r^2S_1}{rN_1} = r\left.\frac{S}{N}\right|_1$$

If it is desired to maintain a combined output signal-to-noise ratio $(S/N)_D$ at the decision-making circuit, then the required redundancy may be determined by

$$r = \frac{(S/N)_D}{(S_o/N_o)} \qquad (5)$$

where $(S/N)_D$ is specified by the error probability, and S_o/N_o is determined by the input signal, input noise, and RAKE integration time.

The data rate d of the system is obviously inversely proportional to the redundancy r. The data rate normalized with respect to the maximum system rate d_{max} is:

$$d/d_{max} = 1/r \qquad (6)$$

Combining Equations (3), (5) and (6):

$$\frac{d}{d_{max}} = \frac{2}{(S/N)_D}\,\frac{S_i}{N_i}\,\frac{1}{\left\{1 + \frac{(1 + N_i/S_i)}{100\tau}\right\}}$$

When frequency averaging is employed over three adjacent channels, the usable time constant τ_f may be reduced by a factor of three from the value of τ.

This normalized data rate d/d_{max} is plotted as a function of S_i/N_i in Figure 11 for various values of τ_f and

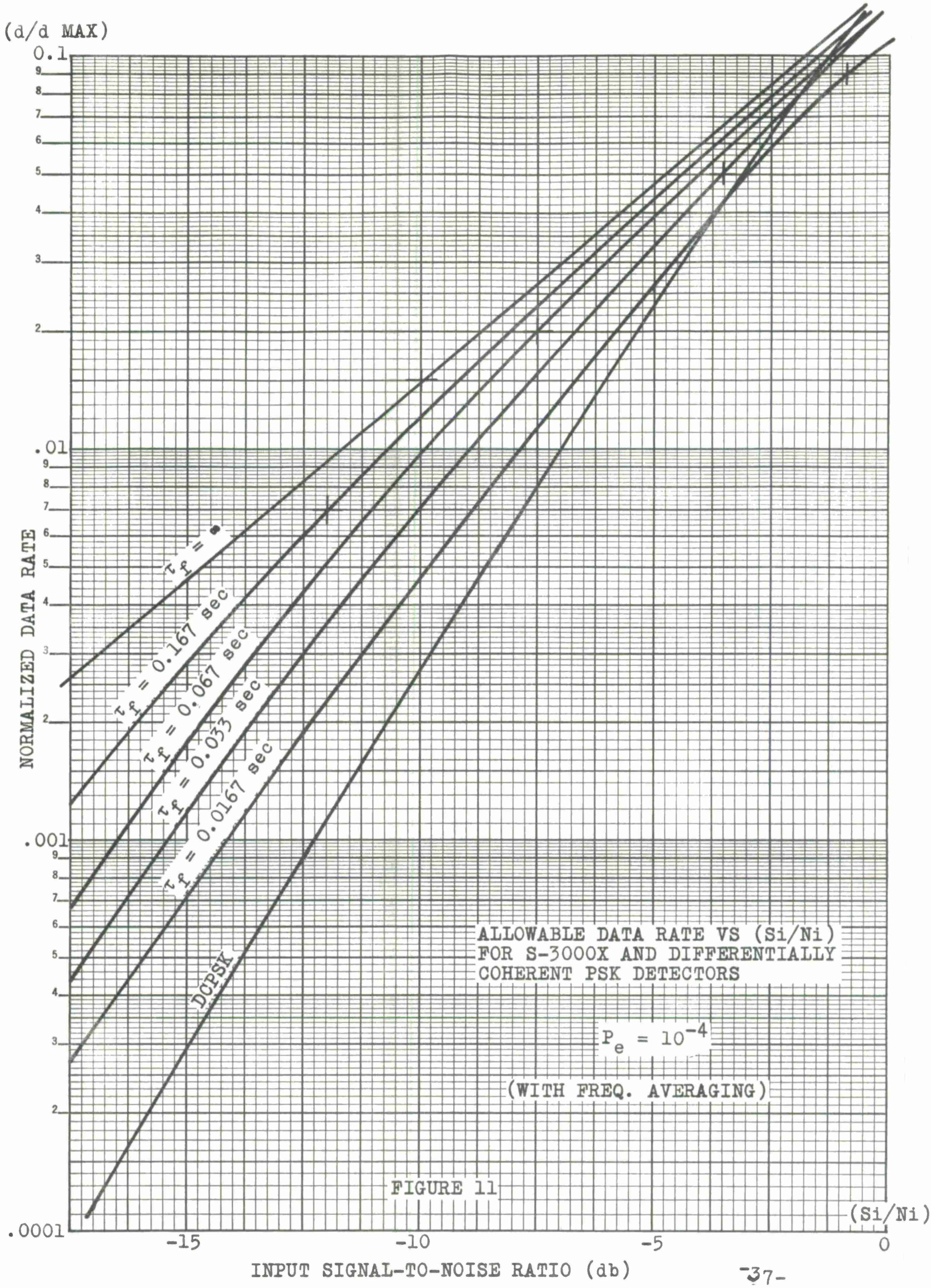

(d/d MAX)
0.1
.01
.001
.0001
NORMALIZED DATA RATE
-15
-10
-5
0
(Si/Ni)
INPUT SIGNAL-TO-NOISE RATIO (db)
$\tau_f = \infty$
$\tau_f = 0.167$ sec
$\tau_f = 0.067$ sec
$\tau_f = 0.033$ sec
$\tau_f = 0.0167$ sec
DCPSK
ALLOWABLE DATA RATE VS (Si/Ni)
FOR S-3000X AND DIFFERENTIALLY
COHERENT PSK DETECTORS
$P_e = 10^{-4}$
(WITH FREQ. AVERAGING)

FIGURE 11

for a value of $(S/N)_D$ of 13.7 which corresponds to a bit error probability of 10^{-4}.

The relationship between bit error probability and correlator output signal-to-noise ratio as expressed in Equation (4) is exact only for a Gaussian noise distribution. The distribution of the noise in a single channel output actually deviates somewhat from the Gaussian distribution when noise is present on both signal and reference. This deviation results in a maximum error for the single channel case of 0.42 db with respect to input signal-to-noise ratio. Any error due to the noise being non-Gaussian is even smaller for redundancy factors >>1 since the distribution of the sum of independent random variables tends to become Gaussian (central limit theorem).

The performance of the S-3000X as calculated from Equation (7) will now be compared to that of a multichannel system employing differentially coherent phase-shifted keyed (DCPSK) signalling. This DCPSK system will be permitted to combine the outputs of independent channels in order to provide improvement of signal-to-noise ratio prior to detection. The DCPSK detector operates by multiplying the signal element being received by the stored previous element, and is in effect a correlator with identical signal-to-noise ratios at its signal and reference inputs. The output signal-to-noise ratio is, from Equation (2),

$$(S_o/N_o)_{DCPSK} = 2\,\frac{S_i}{N_i}\,\frac{1}{1 + N_i/S_i} \tag{8}$$

In the DCPSK system both quadrature components of each channel may be used for information transmission, thus doubling the number of available data channels. The normalized data rate is then

$$d/d_{max} = \frac{4}{(S/N)_D}\,\frac{S_i}{N_i}\,\frac{1}{1 + N_i/S_i} \tag{9}$$

Equation (9) has also been plotted in Figure 11 for $(S/N)_D = 13.7$.

The conclusion which may be drawn from the results of this analysis is that for low signal-to-noise ratios where high redundancy is required -- the S-3000X detection method is superior to that of a redundant DCPSK system. At a signal-to-noise ratio of -10 db, the S-3000X offers a data rate advantage of up to 5.5 over the DCPSK detection. Improvements very close to this can be achieved even under rapid fading, since in redundant operation the integration time can be considerably longer than when no redundancy is used. When operating with a signal-to-noise ratio of -15 db the data rate advantage may be 15 to 1. This advantage is the result of the channel measurement and correction inherent in the RAKE circuits, which provide detector performance approaching that of the ideal coherent detector. The loss suffered by the DCPSK detector relative to the S-3000X is the result of a detection process which is essentially noncoherent; it is the same loss which would be present in any noncoherent detector or conventional diversity combining system operating at a low signal-to-noise ratio.

8.0 Reliability Analysis for the Feasibility Model S-3000X Digital Data Transmission System per Contract AF 19(628)-3281

8.1 Digital Circuits

The digital section of the system is constructed with standard digital circuit cards, manufactured by Computer Control Company. To establish the reliability of this part of the system the manufacturer's demonstrated failure rates at maximum ambient of 35°C are used. A listing of the number of different cards in the transmitting terminal and the receiving terminal combined, with their estimated failure rates follows:

Basic Card Type	Qty Series 20+30	FR %/1000 hrs	Total FR	Series 35	FR %/1000 hrs	Total FR
BC	16	.0885	1.416	10	.124	1.240
DI	31	.0587	1.820	10	.082	0.820
DL	13	.0587	0.763	16	.082	1.310
DN	23	.0366	0.840	24	.0515	1.235
FA	10	.1100	1.100	12	.155	1.860
PN	9	.0725	0.652	6	.101	0.606
SR	44	.0885	3.890	44	.124	5.450
DM	3	.0535	0.1695			
DC	1	.0207	0.0207			
CD	2	.0495	0.099			
LP	2	.0730	0.149	2	.105	0.210
ST	14	.0635	0.888			
SM	4	.1380	0.552			
MC				2	.0585	0.117
			12.3582			12.848

Failure rate of digital section Total 25.2062 %/1000 hrs

8.2 Analog Circuits

The analog circuits of the system have been derived from the designs of a previously constructed breadboard of a similar system. All major circuits employ vacuum tubes, the use of transistors is restricted to some low level signal processing, to control circuits and some interface circuits between the analog and digital sections of the system.

The total number of parts (approximately fourteen thousand) in the analog circuits, prohibited individual stress analyses of their use. It was anticipated that the feasibility model would undergo its testing in a controlled environment (ambient temperature between 20° and 25°C).

Overall average estimated failure rates are used for the parts of the analog circuits based upon an ambient of 25°C and moderate stresses.

For the packaged assemblies, such as delay lines in overns, crystal oscillators in ovens, modular operational amplifiers, etc., a representative failure rate for the assembly as a whole is used.

The contractor had to limit his design, testing and alignment to optimizing the analog circuits at room ambient and no further attention could be directed to the stability of the various analog circuits over a wider temperature range. The failure rate of the overall analog section, transmitter and receiver terminal combined, is calculated as follows:

PART TYPE	QTY	FR %/1000 hrs	
Vacuum tube	339	.4	135.6
Transistor	775	.04	31.0
Diode	926	.02	18.52
Resistor	5500	.002	11.0
Resistor, variable	250	.01	2.5
Capacitor	3700	.003	11.1
Inductor	615	.004	2.46
Transformer	250	.05	12.5
RF Connector	464	.003	1.39
Power Connector Pins	600	.001	0.6
Coaxial switches	2	.04	0.08
Delay lines LC	8	.05	0.4
Delay lines quartz in oven	3	.15	0.45
Operational amplifiers	20	.10	2.0
Meter relays	3	.05	0.15

[continued]

PART TYPE	QTY	FR %/1000 hrs	
Meters	11	.05	0.55
Relay low level	6	.05	0.30
Relay time delay	2	.05	0.1
Relay power	2	.05	0.1
Circuit breakers	6	.05	0.3
Crystal oscillators in oven	8	.2	2.4
Quartz crystal in oven	9	.12	1.08
Toggle switches	30	.01	0.3
Selector switch wafers	20	.02	0.4
Tube socket pins	2400	.001	2.4
Blowers	9	.5	4.5
Fuses	31	.01	0.31
Power supply assemblies	8	1.0	8.0
Mechanical filters	3	.05	0.15
Crystal filters	2	.05	0.1
Solder connections	30000	.002	60.0
	Analog Total		310.74
	Digital Total		25.2
			335.94 %/1000 hrs

or an estimated overall MTBF of 300 hours.

8.3 Comments

The equipment was operated continuously for about 1200 hours during its in-plant testing phase.

Tube defects caused a few failures during the beginning of the test, the only other interruptions were due to failures in the temperature control elements of two of the crystal ovens. The ambient temperature during this test was kept at 25°C.

Transportation to the field sites by truck and by air did not cause any damage and both terminals were operating satisfactorily shortly after installation.

The two periods of field testing added about 1500 hours to the operating time of the system.

Both terminals were inoperative a few times for short periods (up to one hour) during the field test because of failures of several vacuum tubes, type 7360, and again by troubles with the Hunt crystal ovens, which all had to be replaced by spare ovens. In overall parts failures the system performed about as well as could be expected considering the calculated MTBF of 300 hours.

However, serious deterioration of the performance of the system at both field sites was caused by temperature fluctuations, far beyond what was anticipated. Especially the transmitting terminal was often subjected to an ambient change of 25°F in less than six hours, which caused serious drifts in frequency, phase and amplitude of signals in critical analog circuits of the Fourier transformer. As a result the characteristics of the transmitted signals and the processing of the received signals was sufficiently affected to give a serious degradation in error rate performance.

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13. ABSTRACT

The S-3000X Prototype HF Digital Data Modem is a breadboard test model which provides a simulation of 3000 b/s transmission on a high frequency radio voice circuit while actually transmitting 1200 b/s or 750 b/s. A provision has been made for redundant transmission at lower rates for comparison purposes. This final report covers the system specification, critical subsystem and component specifications, laboratory evaluation, a performance analysis and a reliability analysis of the S-3000X modem.

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